ORIGINAL ARTICLE

Ecological-dynamic approach in rhythmic gymnastics: Variation and variability for performance improvement

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ABSTRACT

The aim of the study is to compare, from an ecological-dynamic perspective, two run-up techniques (chassè and pre-jump) used to perform the split leap, aiming at improving performance in rhythmic gymnastics. The sample consists of six competitive gymnasts with an average age of 17.3 years (±1.9). The study used the integrated multifactorial optoelectronic system, consisting of six BTS Smart-DX video cameras, seven BTS-6000 force platforms, and fifteen passive markers. The results show that the jump performed with the chassè shows higher values in maximum amplitude (171.4° ± 16.5 vs. 167° ± 15.7) and maximum elevation (0.15m ± 0.03 vs. 0.14m ± 0.02) compared to the split leap performed with the pre-jump, even if, from the results obtained by the t-test, it emerged that this difference is not statistically significant (*p* > .05). Furthermore, the results of Cohen's Effect Size show a small effect size. In conclusion, from the results obtained in this study, it could be hypothesized that, since there are no statistically significant differences between the two run-up techniques, both could be used to vary the practice since they don't alter the jump performance. Variation in practice refers to the theoretical framework of the ecological-dynamic approach, which enriches the athlete's motor and technical skills.
Keywords: Performance analysis, Split leap, Run-up techniques, Integrated multifactorial optoelectronic system.

Cite this article as:
Costa, C., Coppola, S., & Vastola, R. (2025). Ecological-dynamic approach in rhythmic gymnastics: Variation and variability for performance improvement. *Journal of Human Sport and Exercise, 20*(3), 905-917. https://doi.org/10.55860/241eef24

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Submitted for publication April 01, 2025.
Accepted for publication May 20, 2025.
Published May 29, 2025.
Journal of Human Sport and Exercise. ISSN 1988-5202.

doi: https://doi.org/10.55860/241eef24

INTRODUCTION

The ecological-dynamic approach defines sports performance as processes of continuous co-adaptations of athletes in space and time to identify the most functional action possibilities to achieve the goal (Duarte et al., 2012). According to this approach, the most relevant information for the decision-making process and action implementation emerges during the continuous interactions between the athlete and the environment (Travassos et al., 2012). Athletes, in fact, defined as complex systems, can exploit information from the environment, bringing out functional models of behaviour in performance contexts (Davids et al., 2013).

The theoretical framework of the ecological-dynamic approach lays the foundations for the study and interpretation of movement pattern variability in athletes (Seifert et al., 2013). Variability is essential because it provides the athlete with the necessary fluctuations (Davids et al., 2003) to adapt skills to the situation (Woods et al., 2020), developing the cognitive and motor spheres. In this way, the athlete can try out different variations of the movement rather than always repeating the same solution to the problem (Chow et al., 2011). In this regard, Bernstein (2014) coined the expression "*repetition without repetition*", that is, repeating the same problem-solving process but not the same solution.

Incorporating variation and variability into training is crucial to adapt the performance to the goal and the environment, prevent injuries and increase motivation, especially in rhythmic gymnastics which is described as a sport where there is a stereotypical repetition of gestures (Morgunova, 2020; Oltean et al., 2017). Rhythmic Gymnastics (RG) has been an Olympic sport since 1984 (Hamza et al., 2020) and is one of the few sports that is practiced only by women in most countries (Cleophas & Visser, 2024). The main characteristics of this sport are fluidity, elegance, harmony, strength, and dynamism (Coppola et al., 2024), expressed through the coordination of body movements with the handling of five apparatuses: rope, hoop, ball, clubs, and ribbon (Agopyan & Ors, 2023). A rhythmic gymnastics competition exercise consists of difficulties of body (DB), difficulties of apparatus (DA), dance steps (S), and dynamic elements with rotation (R). DB includes jumps, balances, and pivots. In this study reference is made to jump DB, considered by Chiriac et al. (2021) as very dynamic motor tasks that represent an essential component of RG performances (Polat, 2018; Santos et al., 2016). Jumps require complex muscular coordination of the lower and upper limbs (Ashby & Heegaard, 2002), strength, explosiveness, speed (Çimen, 2012), and flexibility, which is considered one of the fundamental motor skills in RG (Moraru & Rusu, 2016), as during the flight phase, the gymnast must maintain a fixed and well-defined shape of the DB to be performed (Di Cagno et al., 2008), accompanied by choreographic handling of the apparatus (Nazari, 2019).

The run-up is the phase preceding the jump and can be performed either with a run, especially in the early stages of DB learning, or with the chassè (Coppola et al., 2020). In recent years, a pre-jump (shown in Figure 1a) is also used in competition exercises to make the movement more fluid and faster, allowing for greater speed on the music. Varying the practice by using different run-up techniques enriches the athlete's technical skills, allowing to be flexible and adapt effectively to environmental demands (Newell & James, 2008). After the run-up, the jump involves the take-off phase, which is essential for generating the energy needed to jump. This phase can be performed with the take-off on one-foot or two-feet (Coppola et al., 2024; Akkari-Ghazouani et al., 2022). This is followed by the flight phase, in which the gymnast performs the jump with the possible handling of the apparatus, and the landing phase in which the athlete comes back into contact with the ground, cushioning the landing to avoid lower limb injuries (Błażkiewicz et al., 2019).

One of the favourite jumps by coaches and athletes in RG is the split leap (Örs & Turşak, 2020) that requires great speed, explosive strength, body control, and coordination (Mkaouer et al., 2012). During flight, the gymnast performs a sagittal split, bringing the dominant leg forward and the non-dominant leg back, reaching an amplitude of at least 180° at the highest point of the jump. It is preferable that the split position is horizontal, but the jump is also considered valid by the jury when the 180° amplitude is achieved with one leg above and the other below the horizontal position. This DB has a value of 0.30 points (Code of Points RG 2025-2028).

To enhance sports performance, it is important to investigate the dynamic and kinematic parameters of jumps, especially with technologies that allow for an accurate and detailed quali-quantitative analysis of the task, such as the integrated multifactorial optoelectronic system (also used in this study). In this regard, the study conducted by Coppola et al. (2023) investigated the effectiveness of using this system, considered the gold standard for motion analysis, to analyse the dynamics and kinematics of complex and fast motor tasks such as the split leap in RG.

In the scientific literature, there are studies investigating different aspects of the split leap in RG. In particular, the study conducted by Coppola et al. (2025) assessed the variability (CV%) in this jump performed free body and with the handling of the ribbon.

Aji-Putra et al. (2021) examined the relationship between the degree of flexibility of the lower limbs, the leg length of the gymnasts, and the height of the split leap.

The study by Örs & Turşak (2020) investigated some kinematic parameters of the split leap, including the amplitude and height of the jump, the flight time, the distance travelled during the jump, and the length of the last step. The study by Coppola et al. (2020) also investigated some kinematic parameters such as position, speed, acceleration of the sacrum and the amplitude of the jump, comparing two run-up techniques (chassè and run).

The research by Błażkiewicz et al. (2019) compared two different types of landing from the split leap, one stopped on one lower limb and the second with movements after the jump, to aim for improved performance, avoiding injuries.

However, there are no studies in scientific literature that investigate the pre-jump as a run-up technique for split leap in RG. For this reason, the aim of this study is to compare, from an ecological-dynamic perspective, two run-up techniques: chassè (widely used by gymnasts in competition and already studied in the scientific literature) and pre-jump (not yet investigated in scientific literature) used to perform the split leap to investigate the favourable biomechanical characteristics of jumps, aiming at improving performance in RG. It is hypothesized that the split leap performed with the chassè has greater results in elevation and amplitude than the pre-jump.

MATERIAL AND METHODS

Participants

The study sample consisted of six competitive gymnasts with an average age of 17.3 years (±1.9).

The average height value is 164.8 (±6.0) cm, while the average weight value is 54.7 (±3.6) kg.

The gymnasts belong to the following FGI (Italian Gymnastics Federation) categories: Junior 2 (n = 1), Senior (n = 5).

The gymnasts were randomly selected from a group of n = 20 athletes who took part in competitions during the sports year and who mastered the split leap technique. For all gymnasts, the dominant limb is the right.

The gymnasts trained three times a week for two hours a day and didn't report any injuries in the period prior to acquisitions.

The athletes signed the informed consent form, authorizing their participation in the study. In the case of underage athletes, the form was signed by their parents.

The study was conducted in accordance with the Declaration of Helsinki (2013) and has been approved by the Ethical Committee of the Department of Human Sciences, Philosophy & Education at the University of Salerno (protocol number: 0354235).

Instruments

The integrated multifactorial optoelectronic system consisting of six BTS Smart-DX video cameras, seven BTS-6000 force platforms, fifteen passive markers applied to the athletes' bodies following the Simple Helen-Hayes protocol, and two BTS-Vixta video support cameras was used for the study (BTS S.p.A., Italy).

Procedure

The study was conducted at the Laboratory for Innovative Teaching Methodologies and Analysis of Sports Performance, University of Salerno (Italy).

A preliminary pilot investigation was carried out to verify the correct administration of the motion analysis protocol in the same laboratory and on a sample similar to the one considered for the study.

A meeting was organized with the participating athletes (in the case of underage athletes with their parents/tutors) to provide all the necessary information regarding the study to be carried out.

Initially, the following anthropometric measurements of the athletes were taken: body weight, height, total leg length (measuring the distance between the anterior superior iliac spines and the medial malleoli), pelvis width (measuring the distance between the anterior superior iliac spines with a pelvimeter), pelvis height (taking the measurement perpendicular to a ruler placed parallel to the table passing through the greater trochanter and the anterior superior iliac spine), the diameter of the knee (measuring the distance between the femoral epicondyles of the knee) and the diameter of the ankle (measuring the distance between the medial and lateral malleoli) (Kadaba et al., 1990).

Subsequently, the gymnasts performed a standardized warm-up of the muscles involved in the chosen motor task, with reference to the muscle activation of the lower limbs.

Markers were then applied to the athletes' body following the Simple Helen-Hayes protocol (BTS S.p.A., Italy). Markers were placed on the S2, on the anterior-superior iliac spines, on the lateral femoral epicondyles, on the lateral malleoli, on the heels, and in the space between the second and third metatarsal heads. In addition, four rigid bars covered with markers were used and placed on the thighs (in alignment with the greater trochanter of the femur and the marker on the epicondyle) and on the legs (in alignment with the marker on the epicondyle and the one on the lateral malleolus), respectively, to avoid errors in the calculation of the hip intra-extra rotation and knee flexion-extension angles (Kadaba et al., 1990).

After performing a static acquisition with the subjects in orthostasis on the force platforms, five split leap trials with the chassè and five trials of the same task with the pre-jump were performed. Two minutes of recovery were given between the split leap with the chassè and the split leap with the pre-jump. All gymnasts performed a split leap with the right leg forward (dominant limb) and the left leg back.

Data analysis

A quali-quantitative analysis of the motor task was performed. Initially, through a qualitative analysis of the video, the three best jump trials in terms of well-defined form during flight were selected. Subsequently, we moved on to the quantitative analysis, using the SMARTtracker and SMARTanalyzer software (BTS S.p.A., Italy). The first allowed the reconstruction of the gesture, assigning a name to each marker according to the Simple Helen-Hayes protocol (as shown in Figure 2) and the identification of the Ground Reaction Force (GRF). With the SMARTanalyzer software, the modified Helen-Hayes calculation protocol was used to obtain the maximum jump amplitude (°) and the maximum elevation (m) data. In particular, the maximum amplitude was taken as the sum of the angles of hip flexion (for the front limb) and extension (for the back limb). The maximum elevation was calculated as the difference between the maximum height recorded by the marker on S2 after the take-off from the ground and the height recorded by the same marker at the take-off.

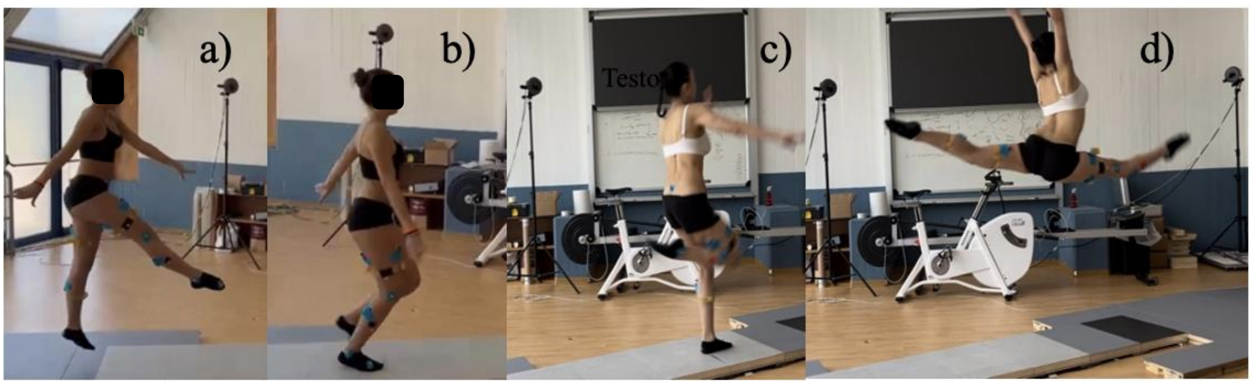

Figure 1. Representation of the phases of the split leap performed with the pre-jump: a) the pre-jump; b) the foot contact; c) the step forward with the opposite leg; d) the split leap.

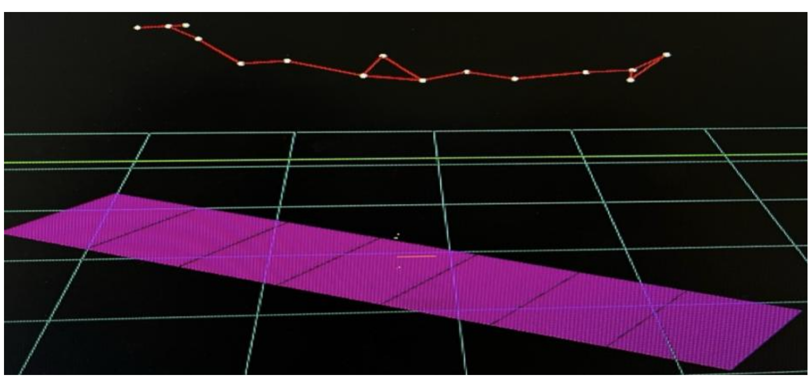

Figure 2. Representation of split leap with SMARTtracker software.

Using descriptive statistics, for each gymnast, the average values and the standard deviation (mean ± SD) of the three best jump trials were reported both for a split leap performed with the chassè and with the pre-jump. The mean and standard deviation (mean ± SD) of the whole sample were also reported for both the maximum split leap amplitude and the maximum elevation for the jumps performed with chassè and pre-jump.

Finally, with the MATLAB R2024b software (The MathWorks, Inc. 2024) the Cohen's Effect Size and t-test for the independent samples were used to verify if the difference between the mean values of the jumps made with the chassè and with the pre-jump was statistically significant.

Results

Table 1. Comparison of the group average of the maximum jump amplitude (°) performed with the chassè and the pre-jump.

Group average of the maximum jump amplitude performed with the chassè	171.4° ± 16.5
Group average of the maximum jump amplitude performed with the pre-jump	167° ± 15.7

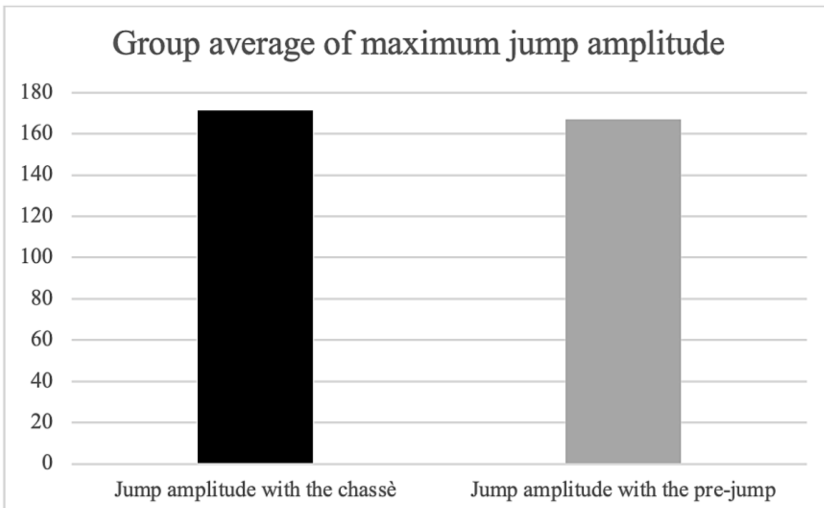

Figure 3. Graphic representation of the group average of the maximum jump amplitude (°) performed with the chassè and the pre-jump.

As shown in Table 1 and Figure 3, the average maximum amplitude (°) of the split leap performed with the chassè (black colour) is greater than the split leap performed with the pre-jump (grey colour) (171.4° ± 16.5 vs. 167° ± 15.7). Specifically, the difference in amplitude between the two run-up techniques is 4.4°.

Table 2. Comparison of the group average of the maximum jump elevation (m) performed with the chassè and the pre-jump.

Group average of the maximum jump elevation performed with the chassè	0.15 m ± 0.03
Group average of the maximum jump elevation performed with the pre-jump	0.14 m ± 0.02

As shown in Table 2 and Figure 4, the average values relative to the maximum elevation (m) of the jump performed with the chassè (black colour) are also higher than the jump performed with the pre-jump (grey colour) (0.15m ± 0.03 vs. 0.14m ± 0.02). In particular, the difference in terms of elevation is 0.01 m.

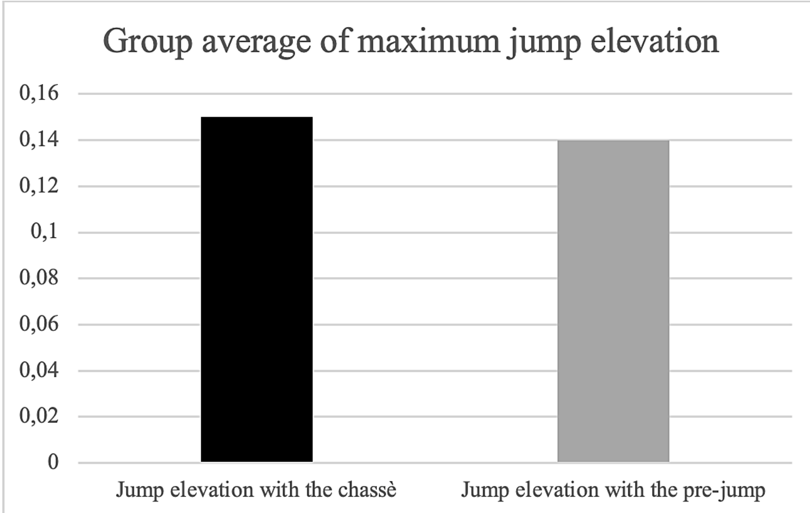

Figure 4. Graphic representation of the group average of the maximum jump elevation (m) performed with the chassè and the pre-jump.

Table 3. *p*-value of the independent samples t-test for the maximum amplitude and maximum elevation of the jump performed with the chassè and with the pre-jump.

***p*-value of the t-test of the maximum jump amplitude**	.6
***p*-value of the t-test of the maximum jump elevation**	.5

Table 3 shows the independent samples t-test *p*-values for the maximum split leap amplitude (0.6) and the maximum jump elevation (0.5).

Table 4. Cohen's Effect Size for the maximum amplitude and maximum elevation of the split leap.

Cohen's Effect Size of the maximum jump amplitude	0.4
Cohen's Effect Size of the maximum jump elevation	0.4

Table 4 shows the values of Cohen's Effect Size for the maximum amplitude and maximum elevation of the split leap performed with the chassè and with the pre-jump.

DISCUSSION

The purpose of this study is to compare, from an ecological-dynamic perspective, two run-up techniques (chassè and pre-jump) used to perform the split leap in rhythmic gymnastics (RG) to investigate the favourable biomechanical characteristics of jumps, aiming at improving performance.

From the results obtained, the jumps performed with the chassè have higher values in amplitude (Table 1 and Figure 3) and elevation (Table 2 and Figure 4) than those performed with the pre-jump (171.4°±16.5 vs. 167° ± 15.7; 0.15m ± 0.03 vs. 0.14m ± 0.02). These results are in line with the research hypothesis that split leap has higher results in elevation and amplitude with the chassè than the pre-jump. This could be because the run-up with the chassè, compared to the pre-jump, allows for the generation of a greater propulsion of the jump, and, consequently, the split leap could be better in elevation and amplitude. As described in the study by Marinho et al. (2021) chassè is a sliding step in which the back foot must catch up with the front foot as if chasing it. Upon contact with the floor, a countermovement is made that allows the hip, knee, and ankle muscles to actively extend and store energy. Next, the hips, knees, and ankles move rapidly into triple extension, and the muscles actively shorten, releasing energy (Weigand & Mokha, 2024). In this regard, the propulsion generated by the chassè is fundamental because, during the flight phase, the gymnast must have a fixed and well-defined shape of the jump (Code of Points RG 2025-2028; Di Cagno et al., 2008) to avoid penalties from the jury.

Although there are no studies in scientific literature that investigate the pre-jump as a run-up technique for split leap in RG, the results of this study are in line with the research by Coppola et al. (2020), in which split leap had a greater total elevation with the chassè compared to running, and also the hip flexion-extension angle was greater with the chassè. The study by Weigand & Mokha (2024), performed in dance, showed that the chassè is one of the most effective run-up techniques to perform the grand jeté jump. In this way, also in the study by Rice et al. (2021), it is described that, to perform a split leap, dancers typically use the chassè. Also, as described in the study by He et al. (2022) on table tennis, the chassè showed higher values in plantar force and peak pressure during the forward phase compared to a single step.

The results of the t-test (Table 3) show that the *p*-values are higher than .05 ($p > .05$), so there is no statistically significant difference (Mishra et al., 2019) between the two run-up techniques in maximum amplitude (0.6) and maximum jump elevation (0.5).

Furthermore, the results of Cohen's Effect Size (Table 4) show a small effect size according to McGuigan's study (2017). These could be due to the small sample size of the study (Garamszegi et al., 2012), which doesn't allow representative conclusions to be drawn for the population of gymnasts. The small sample size reduces statistical power and increases the probability of type II errors (Andrade, 2020), which could explain the lack of significant results despite some observed differences. The effect size is important because it provides a clearer picture of the difference between the groups (Kraft, 2020), which is crucial to understanding the practical significance of the results. Although a small effect size might suggest a slight difference between the two techniques, based on the data collected, it is not possible to conclude that one technique is superior to the other in a statistically significant way.

As there are no statistically significant differences between the split leap performed with the chassè and the pre-jump in elevation and amplitude, it could be hypothesized that both could be used because they provide different movement opportunities without altering performance. In this way, therefore, as described in the theoretical framework of the ecological-dynamic approach, it is important to vary the sporting practice to allow the athlete to adapt effectively to changing environmental demands (Woods et al., 2020; Araujo et al., 2020; Glazier & Davids, 2009; Davids et al., 2003), to prevent injuries (Nordin & Dufek, 2019; Bartlett et al., 2007; James, 2004), and to increase motivation (Bosch, 2021; Studenka et al., 2017), facing the monotony resulting from the stereotyped repetition of the same gesture, typical of gymnastics (Morgunova, 2020; Oltean et al., 2017). Variability provides the movement system with good adaptability and flexibility (Newell & James, 2008). Through variable training, in fact, athletes can try different variations of the movement (Chow et al., 2011).

Variation and variability are important because, especially in competition, the gymnast must make decisions and adjustments in her exercise as quickly as possible. Therefore, having a wide repertoire of choices allows the athlete to adapt to the situation as quickly as possible (McCosker et al., 2020). The ecological-dynamic approach highlights the importance of movement variation and variability in sport training to allow the gymnast to adapt performance to the environment and the goal to be achieved.

As for the practical implications, coaches should encourage gymnasts to try both run-up techniques to perform split leap, because, as described in the ecological-dynamic approach, it is important to adapt movements to both internal and external factors (Bartlett et al., 2007; Davids et al., 2003), allowing the gymnast to respond quickly to changing conditions and constraints. In this way, alternating between the chassè and pre-jump techniques can offer a significant advantage in developing a versatile, adaptable, and efficient movement pattern. The chassè could be used to maximize the effectiveness of the jump in terms of amplitude and elevation, while pre-jump could be used for the choreographic needs of the exercise or when the gymnast is too close to the red line on the floor and cannot cross it (otherwise the athlete would have a penalty from the jury). Trying both run-up techniques would lead to gymnasts being more flexible and adapting to different situations (Woods et al., 2020). In addition, the possibility of alternating between the chassè and the pre-jump could help to maintain high motivation and variety in training, reducing the risk of injuries due to repetitive movements, promoting a balanced, safe, and stimulating training for athletes.

CONCLUSIONS

The results of this study show that, although run-up with the chassè has higher values in terms of maximum amplitude and maximum elevation of split leap compared to pre-jump, the t-test shows that there are no statistically significant differences. Therefore, in line with the principles of variation and variability of the ecological-dynamic approach, both run-up techniques could be used to vary the practice without altering performance, reducing the risk of injuries and increasing the possibility of being flexible and adaptable to changes in the environment. Integrating both run-up techniques in the training program promotes a more complete preparation, in which the athlete is not bound to a single movement but develops the ability to adapt to changes, using the most suitable technique for the situation to perform an optimal jump.

The present study is not without limitations, as the small sample size, the acquisitions performed outside the training context (laboratory for human motion analysis), and the speed of the split leap, which required an accurate placement of the markers, blocked by applying tape around them.

In conclusion, future research perspectives in this field could be carried out on a larger sample belonging to different technical levels to investigate the favourable biomechanical characteristics of jumps, aiming at improving training and performance in rhythmic gymnastics. Further research could be carried out by investigating other techniques in rhythmic gymnastics to promote the variation in training and performance from an ecological-dynamic perspective.

AUTHOR CONTRIBUTIONS

The article is the result of a collaborative work by all the authors. CC and SC contributed to the preparation and research design, data collection, data analysis, result, interpretation and manuscript writing. RV is the scientific coordinator of the study. All authors have read and agreed to the final version of the manuscript and consent to its publication in JHSE.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ETHICAL CONSIDERATIONS

These trials are conducted in accordance with ethical principles of the Declaration of Helsinki. Declaration of Helsinki: Ethical Principles for Medical Research involving human subjects (WMA, 2013). This study has been approved by the Ethical Committee of the Department of Human Sciences, Philosophy & Education at the University of Salerno (protocol number: 0354235).

CONSENT TO PARTICIPATE

The parents of the underage athletes signed an informed consent form, authorizing their participation in the study. The adult athletes signed the consent form autonomously.

DATA AVAILABILITY STATEMENT

Data available on request.

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